PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H01C 7/02, 17/30

A1

(11) International Publication Number: WO 99/31677

(43) International Publication Date: 24 June 1999 (24.06.99)

(21) International Application Number: PCT/US98/26328

(22) International Filing Date: 10 December 1998 (10.12.98)

(30) Priority Data:
08/990,707 15 December 1997 (15.12.97) US

(71) Applicant: RAYCHEM CORPORATION [US/US]; 300 Constitution Drive, Mail Stop 120/1A, Menlo Park, CA 94025-1164 (US).

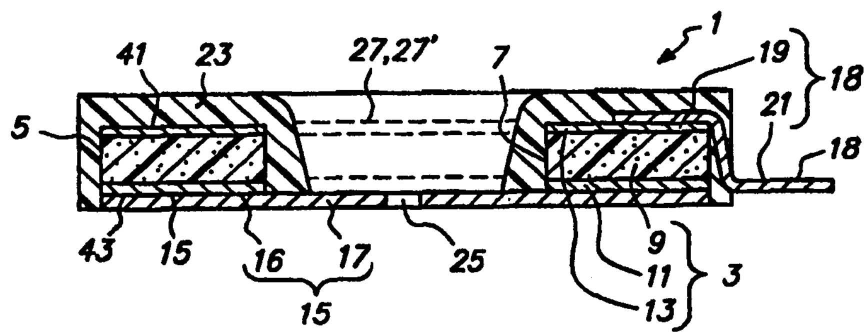
(72) Inventors: MIYASAKA, Naofumi; 2-10-1#120, Misato-dai, Narita, Chiba (JP). FANG, Shou-mean; Sesson Park #20, 2419 Hong Qiao Road, Shanghai 200335 (CN).

(74) Agents: GERSTNER, Marguerite, E. et al.; Raychem Corporation, Intellectual Property Law Dept., 300 Constitution Drive, Mail Stop 120/1A, Menlo Park, CA 94025-1164 (US).

(81) Designated States: CA, CN, JP, KR, MX, SG, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: ELECTRICAL DEVICE



(57) Abstract

An electrical device (1) containing a resistive element (9) composed of a conductive polymer composition which exhibits PTC behavior which is attached to two metal foil electrodes (11, 13). The device is prepared by a method which includes the steps of (a) cutting the device from a laminate containing the conductive polymer composition positioned between two metal foils; (b) exposing the device after the cutting step to at least one thermal excursion from a first temperature which is at most (T_m-100) °C to a second temperature which is at most (T_m-25) °C; and (c) crosslinking the conductive polymer composition after the thermal excursion. The devices of the invention have low resistance and are useful as circuit protection devices.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

ELECTRICAL DEVICE

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to electrical devices comprising conductive polymers, and a method of making such devices.

Introduction to the Invention

Electrical devices which comprise conductive polymer compositions which exhibit PTC (positive temperature coefficient of resistance) behavior are well-known and are used as circuit protection devices and heaters. Such circuit protection devices, containing low resistivity conductive polymer compositions, respond to changes in ambient temperature and/or current conditions. Under normal conditions, a circuit protection device remains in a low temperature, low resistance state when in series with a load in an electrical circuit. When exposed to an overcurrent or overtemperature condition, however, the device increases in resistance, effectively shutting down the current flow to the load in the circuit. For many applications it is desirable that the device have as low a resistance as possible in order to minimize the contribution to the total resistance of the electrical circuit during normal operation. Furthermore, a low resistance allows the device to have a higher hold current, i.e. the largest steady state current that, under specified ambient conditions, can be passed through a circuit protection device without causing the device to "trip" into the high resistance state. Although low resistance devices can be made from a given composition by changing dimensions, e.g. making the distance between the electrodes very small or the device area very large, small devices are preferred. Such devices occupy less space on a circuit board and generally have desirable thermal properties.

BRIEF SUMMARY OF THE INVENTION

The most common technique to achieve a small device is to use a composition that has a low resistivity. It is known that various processing steps, e.g. irradiation, encapsulation, or exposure to elevated temperature during solder reflow, can increase the resistivity of the composition during device fabrication. Therefore, it is desirable to use

processing techniques which increase the resistivity of the composition as little as possible so that the final device will have a low resistance. We have now found a particular sequence of processing steps which helps in producing a device with a low resistance. In a first aspect this invention provides an electrical device which comprises

(A) a resistive element which is composed of a conductive polymer composition which exhibits PTC behavior and which comprises

(1) a polymeric component having a crystallinity of at least 20% and a melting point Tm, and

(2) dispersed in the polymeric component, a particulate conductive filler; and

(B) two electrodes which (i) are attached to the resistive element, (ii) comprise metal foils, and (iii) can be connected to a source of electrical power,

the device having been prepared by a method which comprises the steps of

(a) cutting a device from a laminate comprising the conductive polymer composition positioned between two metal foils;

(b) exposing the device after the cutting step to at least one thermal excursion from a first temperature which is at most $(T_m - 100)$°C to a second temperature which is at most $(T_m - 25)$°C; and

(c) crosslinking the conductive polymer composition after the thermal excursion.

In a second aspect, the invention provides a method of making an electrical device which comprises

(A) a resistive element which (i) has a thickness of at most 0.51 mm, (ii) is crosslinked to the equivalent of at least 2 Mrads, and (iii) is composed of a conductive polymer composition which comprises

(1) a polymeric component having a crystallinity of at least 20% and a melting point T_m, and

(2) dispersed in the polymeric component, a particulate conductive filler; and

(B) two electrodes which (i) are attached to the resistive element, (ii) comprise metal foils, and (iii) can be connected to a source of electrical power,

said method comprising

(a) cutting a device from a laminate comprising the conductive polymer composition positioned between two metal foils,

(b) exposing the device after the cutting step to at least one thermal cycle from a first temperature which is at most $(T_m - 100)$°C to a second temperature which is at most $(T_m - 25)$°C and back to the first temperature, and

(c) crosslinking the conductive polymer composition after the thermal cycle step.

In third aspect, the invention provides a battery assembly which comprises

(I) a battery which comprises first and second terminals; and

(II) a device according to the first aspect of the invention which further comprises

(C) a first conductive lead which is attached to the first electrode, and

(D) a second conductive lead which is attached to the second electrode;

said device having been placed in contact with the first terminal of the battery so that the first conductive lead is in physical and electrical contact with that terminal.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is illustrated by the drawings in which Figure 1 is a cross-sectional view of a device of the invention;

Figure 2 is a top view of a device of the invention;

Figure 3 is a top view of a first conductive lead which forms part of a device of the invention;

Figure 4 is a top view of a device of the invention with a second conductive lead attached;

Figure 5 is a top view of a device of the invention comprising an insulating layer; and

Figure 6 is a graph showing the resistance distribution for devices made by a method of the invention and two comparative methods.

DETAILED DESCRIPTION OF THE INVENTION

The electrical device of the invention comprises a resistive element composed of a conductive polymer composition, and first and second metal foil electrodes which are attached to, and sandwich, the resistive element. The conductive polymer composition comprises a polymeric component, and dispersed therein, a particulate conductive filler. The polymeric component comprises one or more polymers, one of which is preferably a crystalline polymer having a crystallinity of at least 20% as measured in its unfilled state by a differential scanning calorimeter. Suitable crystalline polymers include polymers of one or more olefins, particularly polyethylene such as high density polyethylene; copolymers of at least one olefin and at least one monomer copolymerisable therewith such as ethylene/acrylic acid, ethylene/ethyl acrylate, ethylene/vinyl acetate, and ethylene/butyl acrylate copolymers; melt-shapeable fluoropolymers such as polyvinylidene fluoride (PVDF) and ethylene/tetrafluoroethylene copolymers (ETFE, including terpolymers); and blends of two or more such polymers. For some applications it may be desirable to blend one crystalline polymer with another polymer, e.g. an elastomer or an amorphous thermoplastic polymer, in order to achieve specific physical or

thermal properties, e.g. flexibility or maximum exposure temperature. The polymeric component generally comprises 40 to 90% by volume, preferably 45 to 80% by volume, especially 50 to 75% by volume of the total volume of the composition.

The particulate conductive filler which is dispersed in the polymeric component may be any suitable material, including carbon black, graphite, metal, metal oxide, conductive coated glass or ceramic beads, particulate conductive polymer, or a combination of these. The filler may be in the form of powder, beads, flakes, fibers, or any other suitable shape. The quantity of conductive filler needed is based on the required resistivity of the composition and the resistivity of the conductive filler itself. For many compositions the conductive filler comprises 10 to 60% by volume, preferably 20 to 55% by volume, and for low resistivity compositions used for low resistance circuit protection devices, especially 25 to 50% by volume of the total volume of the composition.

The conductive polymer composition may comprise additional components, such as antioxidants, inert fillers, nonconductive fillers, radiation crosslinking agents (often referred to as prorads or crosslinking enhancers, e.g. triallyl isocyanurate), stabilizers, dispersing agents, coupling agents, acid scavengers (e.g. $CaCO_3$), or other components. These components generally comprise at most 20% by volume of the total composition. Dispersion of the conductive filler and other components into the polymeric component may be achieved by any suitable means of mixing, e.g. melt-processing or solvent-mixing. The mixed composition can be melt-shaped by any suitable method, e.g. melt-extrusion, injection-molding, compression-molding, or sintering, in order to produce a resistive element. The element is preferably laminar and may be of any shape, e.g. rectangular, square, circular, or annular. The resistive element often has a thickness of at most 1.02 mm (0.040 inch), and, for many applications, is much thinner, i.e. has a thickness of at most 0.51 mm (0.020 inch), preferably at most 0.38 mm (0.015 inch).

The composition used in the resistive element exhibits positive temperature coefficient (PTC) behavior, i.e. it shows a sharp increase in resistivity with temperature over a relatively small temperature range. In this application, the term "PTC" is used to mean a composition or device which has an R_{14} value of at least 2.5 and/or an R_{100} value of at least 10, and it is preferred that the composition or device should have an R_{30} value of at least 6, where R_{14} is the ratio of the resistivities at the end and the beginning of a 14°C range, R_{100} is the ratio of the resistivities at the end and the beginning of a

100°C range, and R_{30} is the ratio of the resistivities at the end and the beginning of a 30°C range. Generally the compositions used in devices of the invention show increases in resistivity which are much greater than those minimum values.

Suitable conductive polymer compositions are disclosed in U.S. Patent Nos. 4,237,441 (van Konynenburg et al), 4,545,926 (Fouts et al), 4,724,417 (Au et al), 4,774,024 (Deep et al), 4,935,156 (van Konynenburg et al), 5,049,850 (Evans et al), 5,250,228 (Baigrie et al), 5,378,407 (Chandler et al), 5,451,919 (Chu et al), 5,582,770 (Chu et al), 5,747,147 (Wartenberg et al), and 5,801,612 (Chandler et al), and in commonly assigned International Publication No. WO96/29711 (Raychem Corporation, published September 26, 1997).

The resistive element is attached to first and second laminar electrodes which are attached to the first face and the second face, respectively, of the resistive element. It is preferred that the conductive polymer composition be extruded or otherwise formed into a sheet onto which the electrodes may be attached to form a laminate, i.e. the conductive polymer is sandwiched between the foils. Both first and second electrodes comprise a conductive material, and are preferably metal in the form of a foil, e.g. nickel, copper, brass, stainless steel, or an alloy of one or more of these metals, although one or both of the electrodes may comprise a conductive paint or graphite layer. A tie layer, e.g. a conductive adhesive, may be used to attach the electrode to the resistive element. It is particularly preferred that the first and second electrodes comprise an electrodeposited metal foil, e.g. nickel, copper, or nickel-coated copper. Appropriate electrodes are disclosed in U.S. Patents Nos. 4,689,475 (Matthiesen) and 4,800,253 (Kleiner et al), and in International Publication No. WO95/34081 (Raychem Corporation, published December 14, 1995).

The device may also comprise an insulating layer, which provides electrical and environmental protection to the device. The insulating layer generally covers some or all of the metal foil electrodes and any exposed surfaces of the resistive element. Suitable insulating materials include polymers such as polyamide, polybutylene terephthalate, a polyester, polyethylene, polyvinylidene fluoride, liquid crystalline polymers, or an epoxy resin.

In the method of the invention, in a cutting step, the device is cut from a laminate comprising the conductive polymer composition positioned between two metal foils. In

this application, the term "cutting" is used to include any method of isolating or separating the resistive element of the device from the laminate, e.g. dicing, punching, shearing, cutting, etching and/or breaking as described in International Publication No. WO95/34084 (published December 14, 1995).

The device is then subjected to a thermal treatment step. The thermal treatment step comprises at least one excursion from a first temperature T_1 to a second temperature T_2. Preferably the thermal treatment step includes a return to the first temperature after exposure to the second temperature, thus creating a cycle from T_1 to T_2 to T_1. The first temperature is at most $(T_m - 100)$°C, preferably at most $(T_m - 120)$°C, particularly at most $(T_m - 150)$°C, where T_m is the melting point of the polymeric component, as measured by the peak of the endotherm of a differential scanning calorimeter. When there is more than one peak, for example when the polymeric component comprises a mixture of crystalline polymers, T_m is defined as the temperature of the highest temperature peak. The second temperature is at most $(T_m - 25)$°C, preferably at most $(T_m - 35)$°C, particularly at most $(T_m - 50)$°C. It is important that the first temperature be at a temperature above the glass transition temperature T_g of the polymeric component. T_1 is often at a temperature below room temperature, i.e. less than 20°C. In a preferred embodiment of the method, the device is exposed to at least two thermal cycles, preferably at least three thermal cycles. For some applications, the device may be exposed to many more thermal cycles, e.g. six thermal cycles. During the thermal treatment step, for the thermal excursion or for each thermal cycle, the device is held at both the first and the second temperatures for sufficient time to ensure that the entire device reaches the designated temperature. The time period during which the device is held may be the same or different at T_1 and T_2, but is generally at least 1 minute, preferably at least 3 minutes, more preferably at least 5 minutes, particularly at least 10 minutes, more particularly at least 15 minutes, especially at least 30 minutes, e.g. 60 minutes, as measured from the time the device reaches the designated temperature. Any suitable heat source may be used during the thermal treatment step, e.g. an oven (particularly a programmable oven) or other environmental chamber, or a heat lamp. The rate of temperature increase from T_1 to T_2 (and back to T_1, if present), may be any convenient rate, e.g. 2 to 30°C/minute. When the thermal treatment step is a thermal cycle, the rate from T_1 to T_2 may the same as or different from the rate from T_2 to T_1.

Following the thermal treatment step, the conductive polymer composition is crosslinked. Crosslinking can be accomplished by chemical means or by irradiation, e.g. using an electron beam or a Co^{60} γ irradiation source. The level of crosslinking depends on the required application for the composition, but is generally less than the equivalent of 200 Mrads, and is preferably substantially less, i.e. from 1 to 20 Mrads, preferably from 1 to 15 Mrads, particularly from 2 to 10 Mrads for low voltage (i.e. less than 60 volts) applications. Useful circuit protection devices for applications of less than 30 volts can be made by irradiating the device to at least 2 Mrads but at most 10 Mrads.

For many applications, it is necessary to attach at least one conductive lead, i.e. a first conductive lead, to one of the metal foil electrodes. Often first and second conductive leads are attached to first and second electrodes, respectively. The conductive leads allow easy connection of the electrodes to the source of electrical power, e.g. a battery or a power source, or into the circuit, and can be used to control the thermal output of the device. The conductive leads, which often are supplied as part of a lead frame for ease in manufacture, are preferably attached to the electrodes by means of an intermediate layer, e.g. solder or a conductive adhesive. This lead attachment step preferably occurs after the cutting step and before the thermal treatment step. Other assembly processes, e.g. application of the electrically insulating layer such as an epoxy resin or other polymer, are preferably conducted during an assembly step, which includes the lead attachment step and occurs after the cutting step and before the thermal treatment step.

Following the method of the invention, devices in which the conductive polymer has a low resistivity, i.e. less than 100 ohm-cm, preferably less than 20 ohm-cm, particularly less than 10 ohm-cm, more particularly less than 5 ohm-cm, especially less than 2 ohm-cm, e.g. less than 1 ohm-cm, can be prepared. For most applications, the device generally has a resistance at 20°C of less than 1 ohm, preferably less than 0.5 ohms, particularly less than 0.25 ohms, e.g. 0.050 to 0.150 ohms.

Devices of the invention are particularly suitable for use in a battery assembly, in which the device is preferably attached to the first or second terminal of a battery. The attachment may be directly between the battery and the first or second electrode, or between the battery and the first conductive lead which is attached to the first electrode, or the second conductive lead which is attached to the second electrode. For some batteries, in which either the first and/or the second terminal is in the form of a "button", the device is physically and electrically attached to a button terminal. The device may be

attached to either the negative or the positive terminal of the battery. Batteries suitable for use include nickel-cadmium, nickel-metal hydride, alkaline, or lithium batteries. Often the battery assembly comprises two or more batteries. Such a battery assembly is shown in International Publications Nos. WO97/06538 (K.K. Raychem, published February 20, 1997) and WO98/20567 (Raychem Corporation, published May 14, 1998).

The invention is illustrated by the drawings in which Figure 1 shows in cross-section electrical device 1 of the invention comprising PTC component 3, first conductive lead 15, second conductive lead 18, and insulating material 23. PTC component 3 comprises first electrode 11, second electrode 13 and resistive element 9 composed of a conductive polymer sandwiched therebetween. In PTC component 3 shown in Figure 1, both electrodes opposing each other form first surface 43 and second surface 41.

A top view of PTC component 3 is shown in Figure 2. PTC component 3 comprises surfaces 41 and 43, outer periphery 5 and inner periphery 7 and is in the form of a disk with an opening 27 in the center. The inner periphery 7 defines the opening 27.

Figure 3 shows a top view of first conductive lead 15, which has a first part 16 which is attached to first electrode 11, and a second part 17 which extends across opening 27 of PTC component 3. In this embodiment, first part 16 covers the whole surface of first electrode 11. Second part 17 of first lead 15, which covers at least a part of opening 27, is used to make direct electrical contact, via solder, pressure, or a weld, to a button terminal of a battery. The second part 17 covers at least a part of opening 27.

Figure 4 shows a top view of second conductive lead 18, which comprises first part 19 and second part 21. First part 19 is attached to second electrode 13 and covers at least part of the surface of second electrode 13. Second part 21 extends away from outer periphery 5 and can be bent, if necessary, to make electrical contact to a second battery or other electrical component. First and second conductive leads 15,18 can be made from any suitable material, e.g. nickel, stainless steel, copper, or an alloy such as brass or bronze. For ease of manufacture second lead 18 is often part of a lead frame.

Figure 5 shows a top view of device 1 which as been encapsulated by electrically insulating layer 23. When a positive terminal of a battery is placed inside opening 27', no short circuit occurs because no electrical contact is made between the terminal and PTC component 3.

The invention is illustrated by the following examples, in which Examples 1 and 2 are comparative examples. The following steps were conducted for each example:

Preparation of PTC Device

A first compound was prepared by preblending 54% by weight carbon black (Raven™ 430U, available from Columbian Chemicals) with 46% by weight high density polyethylene (Petrothene™ LB832, available from Millenium; "HDPE") in a Henschel blender, mixing the blend in a Buss kneader, and extruding into pellets. A second compound was prepared by preblending 51.4% by weight carbon black with 48.6% by weight HDPE in the same way. Pellets of the first and second compounds were preblended to give a final compound having 52.7% by weight carbon black and 47.3% by weight HDPE, and this compound was extruded through a sheet die using an Egan extruder to give a sheet with a thickness of 0.25 mm (0.010 inch). The extruded sheet was laminated between two layers of electrodeposited nickel foil having a thickness of about 0.033 mm (0.0013 inch) (available from Fukuda) by using a press set at 200°C. The laminated sheet was solder-dipped into a solder formulation of 63% lead/37% tin heated to 230°C, and devices having the shape shown in Figure 2 were punched from the laminated sheet.

Assembly of Device

First and second conductive leads, as shown in Figures 3 and 4, were attached to the PTC device by means of 63/37 lead/tin solder, which was reflowed in a hot-air oven which increased in temperature from 30°C to a maximum temperature of 230°C over about 2 minutes. An insulating layer of liquid crystalline polymer was then applied by means of transfer or injection molding.

Irradiation

Devices were irradiated by using a cobalt 60 γ irradiation source to give a total irradiation of 14 Mrad.

Temperature Cycling

The devices were thermally cycled six times, each cycle being from -40 to 80 to -40°C at a rate of 1°C/minute with a 60 minute dwell at -40°C and 80°C.

Examples 1 and 2 (Comparative)

Device preparation was conducted as shown in Table I, with numbers 1 to 4 indicating the sequential order of the process steps as they were conducted. The resistance at 25°C was measured for one hundred devices prepared for each example. The resulting devices had an average resistance at least 5% higher than that of devices of the invention (Example 3).

Example 3

Device preparation was conducted as shown in Table I. The resulting devices had a resistance lower than that of conventional devices. A comparison of the resistance distribution of the devices is shown in Figure 6.

Example	Device Preparation Steps				Resistance (mohms)
	Preparation	Assembly	Irradiation	Temp.Cycle	
1	1	2	3	4	53.3
2	1	3	2	4	64.9
3	1	2	4	3	49.0

Although the various figures and descriptions in this specification relate to specific embodiments of the invention, it is to be understood that where a specific feature is disclosed in the context of a particular figure, such feature can also be used, to the extent appropriate, in the context of another figure, in combination with another feature, or in the invention in general. It will be understood that the above-described arrangements of apparatus and the methods therefrom are merely illustrative of applications of the principles or this invention and many other embodiments and modifications may be made without departing from the spirit and scope of the invention as defined in the claims.

What is claimed is:

1. An electrical device which comprises

(A) a resistive element which is composed of a conductive polymer composition which exhibits PTC behavior and which comprises

(1) a polymeric component having a crystallinity of at least 20% and a melting point T_m, and

(2) dispersed in the polymeric component, a particulate conductive filler; and

(B) two electrodes which (i) are attached to the resistive element, (ii) comprise metal foils, and (iii) can be connected to a source of electrical power,

the device having been prepared by a method which comprises the steps of

(a) cutting a device from a laminate comprising the conductive polymer composition positioned between two metal foils;

(b) exposing the device after the cutting step to at least one thermal excursion from a first temperature which is at most $(T_m - 100)$°C to a second temperature which is at most $(T_m - 25)$°C; and

(c) crosslinking the conductive polymer composition after the thermal excursion.

2. A device according to claim 1 wherein the method further comprises attaching at least one conductive lead to one of the metal foil electrodes after step (a) and before step (b).

3. A device according to claim 1 or 2 which has a resistance of at most 0.100 ohm.

4. A device according to claim 1, 2, or 3 which has been crosslinked in step (c) to the equivalent of 1 to 20 Mrads.

5. A device according to any one of the preceding claims wherein the polymeric component comprises polyethylene, an ethylene copolymer, or a fluoropolymer.

6. A device according to any one of the preceding claims wherein in step (b) the device is exposed to at least one thermal cycle from the first temperature to the second temperature and back to the first temperature.

7. A device according to any one of the preceding claims wherein in step (b) the first temperature T_1 is less than 23°C.

8. A method of making an electrical device according to claim 1 wherein

(1) the resistive element (i) has a thickness of at most 0.51 mm and (ii) is crosslinked to the equivalent of at least 2 Mrads, and

(2) in step (b), the device is exposed to at least one thermal cycle from a first temperature which is at most $(T_m - 100)$°C to a second temperature which is at most $(T_m - 25)$°C and back to the first temperature after the cutting step.

9. A method according to claim 8 wherein in step (b) the device is exposed to at least three thermal cycles.

10. A battery assembly which comprises

(1) a battery which comprises first and second terminals; and

(2) a device according to claim 1 which further comprises (a) a first conductive lead which is attached to the first electrode, and (b) a second conductive lead which is attached to the second electrode;

said device having been placed in contact with the first terminal of the battery so that the first conductive lead is in physical and electrical contact with that terminal.

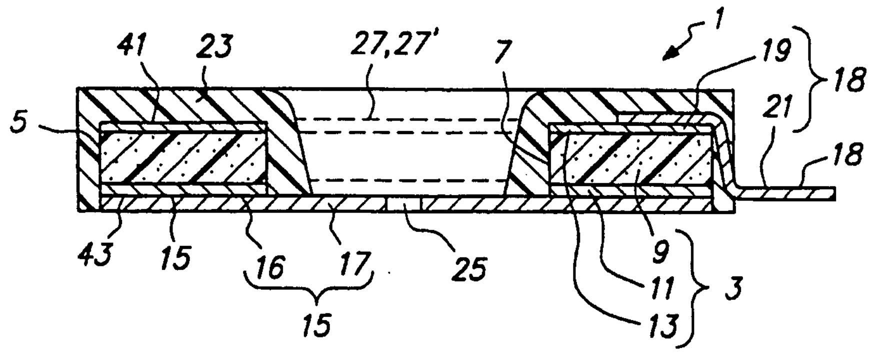

1
41
23
27,27'
7
19
18
5
21
18
43
15
16
17
25
9
11
3
13
15

FIG. 1

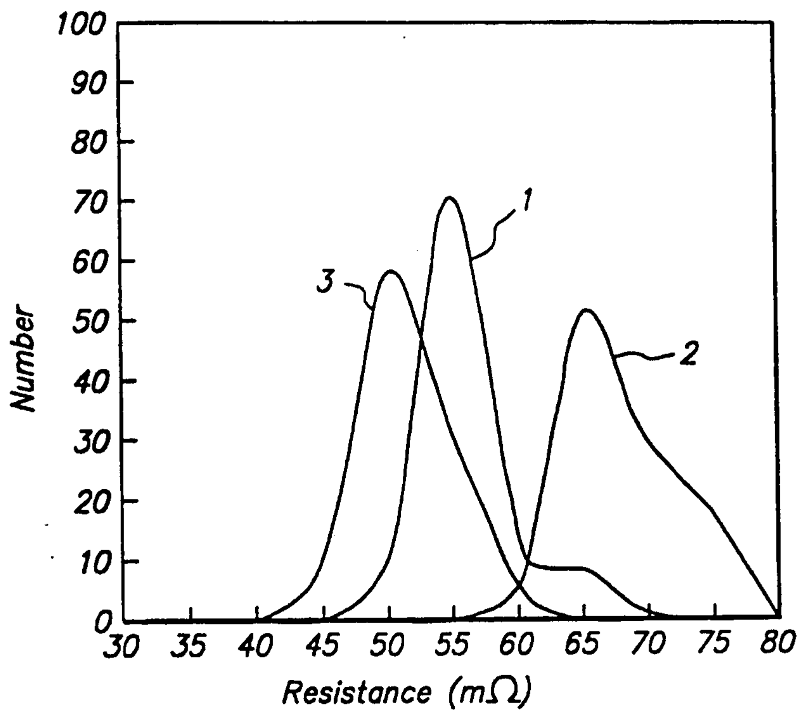

100
90
80
70
60
50
40
30
20
10
0
Number
30 35 40 45 50 55 60 65 70 75 80
Resistance (mΩ)
1
2
3

FIG. 6

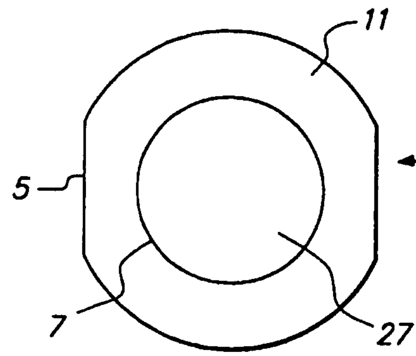


FIG. 2

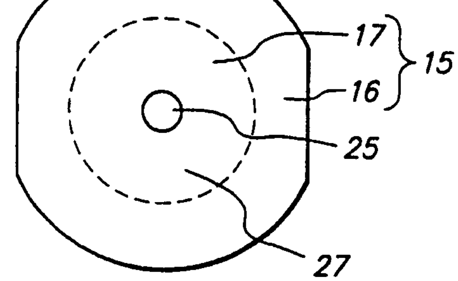


FIG. 3

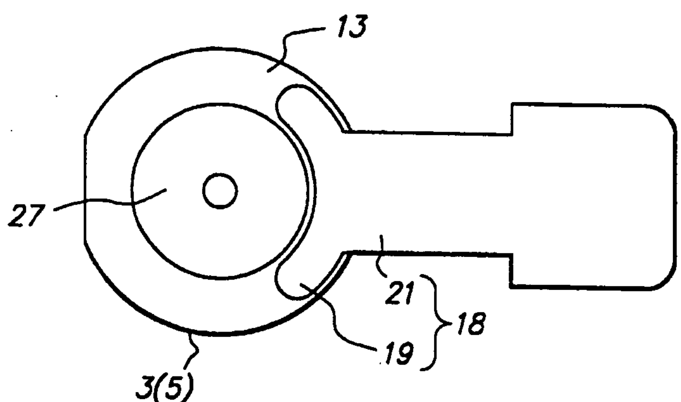


FIG. 4

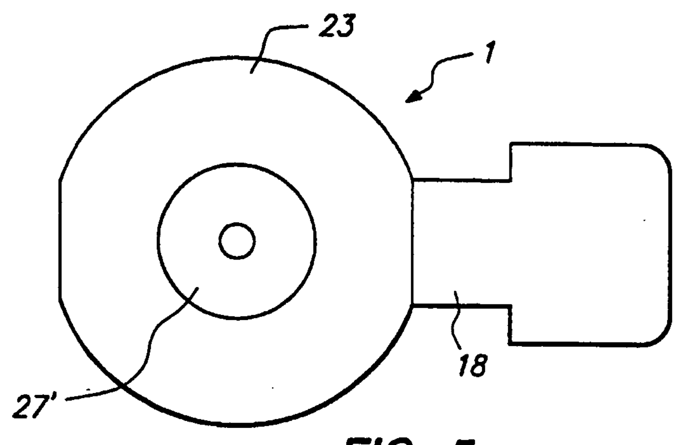


FIG. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/26328

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01C7/02 H01C17/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 522 863 A (DAITO TSUSHINKI KK) 13 January 1993 see page 7, line 35 - page 7, line 44; claims 4,6,8,10; table 5	1,3,5-8
A		4
Y	EP 0 730 282 A (UNITIKA LTD) 4 September 1996 see the whole document	1,3,5-8
A		9
P,A	EP 0 844 622 A (RAYCHEM KK) 27 May 1998 cited in the application see page 6, line 36 - page 9, line 40; claims 1-8; figures 1-10	1,3,5,9

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 March 1999	16/03/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Gorun, M

1

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/26328

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 484 138 A (DAITO TSUSHINKI KK) 6 May 1992 see the whole document	1,5
A	EP 0 344 734 A (MATSUSHITA ELECTRIC IND CO LTD) 6 December 1989 see the whole document	1,4,5

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

I. .onal Application No
PCT/US 98/26328

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0522863 A	13-01-1993	JP 5021207 A	29-01-1993
		DE 69202410 D	14-06-1995
		DE 69202410 T	07-12-1995
		US 5241741 A	07-09-1993
EP 0730282 A	04-09-1996	CA 2170186 A	29-08-1996
		JP 8298201 A	12-11-1996
		US 5817423 A	06-10-1998
EP 0844622 A	27-05-1998	CN 1197534 A	28-10-1998
		WO 9706538 A	20-02-1997
EP 0484138 A	06-05-1992	JP 4167501 A	15-06-1992
		US 5280263 A	18-01-1994
EP 0344734 A	06-12-1989	JP 1304683 A	08-12-1989
		JP 2543135 B	16-10-1996
		JP 2008258 A	11-01-1990
		JP 2035702 A	06-02-1990
		CA 1337012 A	19-09-1995
		DE 68920479 D	23-02-1995
		DE 68920479 T	18-05-1995
		US 5196145 A	23-03-1993